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On the interpretation of century–millennium-scale variations of the Black Sea level during the first quarter of the Holocene

A. Kislov

Lomonosov Moscow State University, Faculty of Geography, Department of Meteorology and Climatology, Lenin Gory 1, 119991 Moscow, Russia

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ABSTRACT

Analysis and synthesis of different paleo evidence has enabled a qualitatively new outline of the Holocene history of the Black Sea (BS). In the early Holocene, the sea level rise was complicated by a series of transgressions and regressions. The question of their origin remains open because there are no clear, stable links of the BS level anomalies and palaeohydrological phases with the calendar of climatic anomalies. Tectonically induced vertical motions may also be a source of discrepancies of different eustatic curves.

Neglecting the water exchange via the Bosphorus Strait at the beginning of the Holocene, we can propose the mechanism of occurrence of large transgressive/regressive stages of the BS. The model of the BS level dynamics is interpreted as stochastic; from this perspective, it is a Langevin equation that incorporates the action of river runoff, precipitation and evaporation as random white noise. Under these conditions, the fast anomalies of the water regime are accumulated by the BS undergoing random walk. This mechanism could be responsible for the appearance of secular-millennium-scale large, irregular fluctuations of the BS level that do not correlate with known climatic events.

However, such hypothetical BS level anomalies could not have occurred in the presence of a large water discharge value via the Bosphorus Strait because intensive water exchange between the BS and the Sea of Marmara was a very effective spin-down process, destroying BS level anomalies and prohibiting the development of large-scale anomalies lasting a few centuries or, furthermore, a few thousand years.

Therefore, the theoretical analysis showed that the empirical data are controversial; observed BS level fluctuations during the first quarter of the Holocene and large water discharge value via the Bosphorus Sill could not occur simultaneously. The magnitude and occurrence of BS level fluctuations and features of the BS–Sea of Marmara interaction require further specification based on geological and geochronological evidence.

1. Introduction

The Black Sea (BS) is a sea between Southeastern Europe and Western Asia. The Bosphorus Strait connects the Black Sea to the Sea of Marmara, and the Strait of Kerch connects that sea to the Sea of Azov. In the past, this basin was an important link in the chain connecting the Caspian Sea and Eastern Mediterranean and played an important role as a part of the Black Sea Mediterranean corridor.

Today, the water exchange with the World Ocean, linking the Black Sea with the Sea of Marmara, is controlled by the two-layer hydraulic transport. The mass balance through the Bosphorus Strait recent reported by Ivanov and Belokopytov (2011) yields an average upper layer outflow of ~420 km^3/y and a lower layer inflow of 200 km^3/y. However, differing estimations exist over the water balance components. For example, Ozsoy and Unluata (1998) yield an average surface layer outflow of ~600 km^3/y and a lower layer inflow of 300 km^3/y. The present water exchange between the BS and the Sea of Azov through the Kerch Strait yield an average outflow of ~40 km^3/y and inflow of ~55 km^3/y (Ivanov and Belokopytov, 2011). The asymmetric transports via mainly the Bosphorus Strait are maintained by the excess river runoff (~355 km^3/y) and evaporation against precipitation $(E-P)$~ (335–220) = 115 km^3/y over the BS area. The water balance is not comparable to the residual of approximately 30 km^3/y. Such conditions provide that the surface of the BS is ~30 cm above the level of the Sea of Marmara, which were directly observed using methods of satellite altimetry (Aksu et al., 2002).

E-mail address: avkislov@mail.ru.

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The BS is mainly swollen by the discharge of European rivers, providing more than 70% of the water runoff. These rivers include the Danube River with a mean water discharge of approximately 210 km^3/y and other rivers off the northwestern shore of the BS (the Dnieper, Dniester and Southern Bug) contributing approximately 54 km^3/y. The Caucasian and Anatolian coast rivers contribute approximately 13 and 10%, respectively.

Snow cover, accumulating during the cold period, mainly forms the annual discharge of major rivers. Atmospheric forcing shapes the variations of snow accumulation as well as variations of precipitation and evaporation over the sea. The BS river catchment area is several times larger than the BS surface, suggesting that the atmospheric circulation over a large part of Europe and the Mediterranean region have an impact on the water balance over such large territory. The important characteristic of the circulation pattern over Europe for winter is the North Atlantic Oscillation (NAO) index. The positive phase of the NAO reflects below-normal pressure across the high latitudes of the North Atlantic and above-normal pressure over the central North Atlantic and Western Europe. The negative phase reflects an opposite pattern of pressure anomalies over these regions. Both phases of the NAO are associated with basin-wide changes in the intensity and location of the polar jet stream, storm tracks and heat and moisture transport, which in turn results in changes in temperature and precipitation patterns extending from Eastern to Western Europe, including the Mediterranean region. Kislov et al. (2009) and Popova et al. (2015) presented examples of the connections between the variability of the NAO and changes in snow cover water equivalent over the Eastern Europe area.

However, an unequivocal pattern in the changes in runoff cannot be obtained based on the NAO index variations alone because the BS lies approximately at the frontier where the dependency of precipitation on the NAO reverses. Indeed, a precipitation index calculated by averaging the annual precipitation over the area, which covers the entire Danube drainage basin, is negatively correlated with the winter NAO index (Rimbu et al., 2004a,b). Conversely, there are positive correlations between precipitation and the NAO index over the Dnieper and Don catchment areas, etc. This means that the rivers feeding the BS adhere to different homogeneous regions (selected based on synchronous behaviour) (Anthropogenic …, 2003). Moreover, the NAO-precipitation patterns represent only the climatological mean. Individual NAO events may vary substantially from these mean patterns. The variations in river runoff and NAO index tend to oppose each other during the entire period of observations with short-term exceptions (for example, 1935–1940), where they are more coherent (Stanev and Peneva, 2002). In addition, the NAO characterizes only part of the variance. Important roles are filled by other circulation patterns (for example, the SCAND index (Popova et al., 2015)); therefore, the actual dynamics of runoff are much more complex and vary in different areas. This motivates us to address here the dependency of the BS level variation on the structure of time variability.

At the Last Glacial Maximum (LGM), during the period of low stand of the World Ocean, the BS evolved independently. Several quantitative estimations of the sea-level regime and mass-balance changes were summarized by Chepalyga (2002), Yanko-Hombach (2007) and Kislov and Toropov (2011). The next phase (after the LGM) of the large-scale transgressive cycle was linked to post-glacial global warming. Low-salinity outflows from the Black Sea into the Marmara Sea were recorded in the early Holocene (Buyukmeric, 2016). Inflow of Mediterranean water to the BS began as occasional spilling over the Bosphorus (~9–7 ka calBP) based on multidisciplinary data from deep basin Black Sea sediments and indirectly from the global sea-level curve (Algan et al., 2007). The two-way flow regime was established due to the confluence of both the Mediterranean and Black Sea overflows. It was slow at the beginning, becoming prominent after ~7 ka calBP.

Reconstructed sea-level changes in the BS basin over the first quarter of Holocene (Fig. 1) have been discussed in many publications. Varushenko et al. (1987) summarized earlier results. When looking at Fig. 1, one finds that half of the curves demonstrate continuous rise without cyclic fluctuations (Aksu et al., 2002; Filipova-Marinova, 2007; Brückner et al., 2010; Starkel et al., 2015). The other half of the curves denote a complex series of transgressions and regressions identified in the paleogeographic records (Chepalyga, 2002; Izmailov, 2005; Balabanov, 2007; Konikov et al., 2010). These level variations (lasting a few centuries to a few thousand years) must correspond to inflow-outflow water mass fluxes because changes in salinity cannot generate BS level fluctuations of

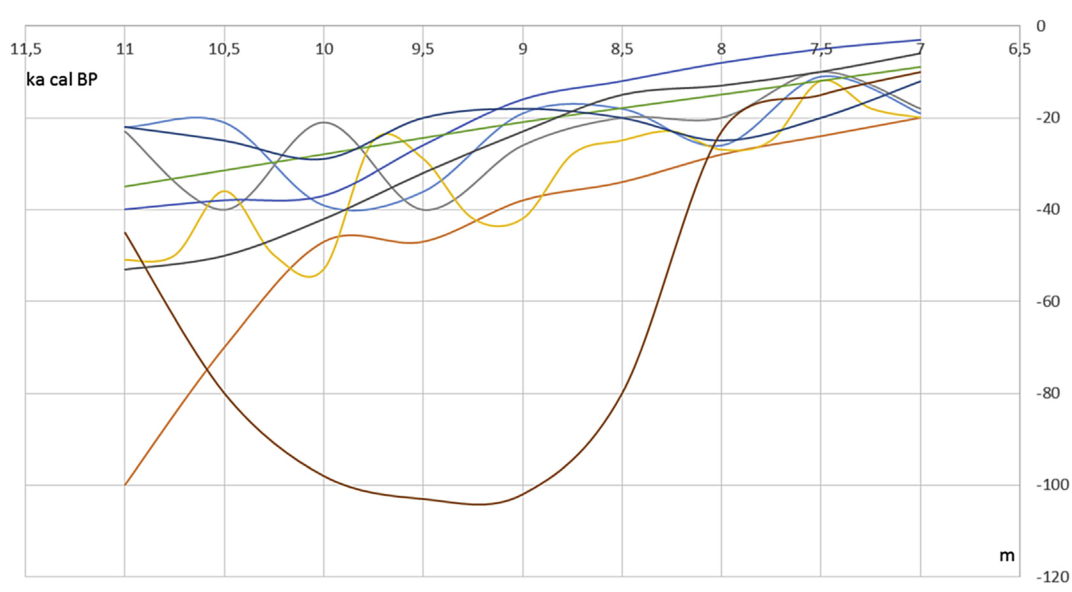

Fig. 1. Paleoeustatic curves of Black Sea level oscillation during 11–7 ka calBP.

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